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Use of the evaporative method for determination of soilless substrate moisture characteristic curves[☆]

Jeb S. Fields (Graduate Research Assistant)[a], James S. Owen Jr. (Assistant Professor)[a,*], Lin Zhang (Graduate Teaching Assistant)[b], William C. Fonteno (Professor)[c]

[a] Department of Horticulture, Virginia Tech, Hampton Roads Agricultural Research and Extension Center, 1444 Diamond Springs Rd., Virginia Beach, VA 23455, United States
[b] Department of Statistics, Virginia Tech, Hutcheson Hall, 250 Drillfield Dr. Blacksburg, VA 24061, United States
[c] Department of Horticultural Science, North Carolina State University, 130 Kilgore Hall, Campus Box 7609, Raleigh, NC 27607, United States

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ABSTRACT

Historically, substrate science has utilized the pressure extraction method to measure soilless substrate moisture characteristic curves, albeit with published discrepancies. Recently, a device utilizing the evaporative method to generate moisture characteristic curves by measuring water potential as volumetric water content decreases via evaporation, known as a Hyprop, has become available. This research compares and contrasts moisture characteristic curves developed over a 2-week period using both the pressure extraction and the evaporative methods for two-component greenhouse (*Sphagnum* peat and perlite) and nursery (aged pine bark and sand) soilless substrates. The pressure extraction method was conducted between water potentials of 0 and −300 hPa (10 data points used in conventional methodology for allotted time), while the evaporative method measurements continued until the tensiometers cavitated (≈ −500 to −700 hPa) and provided higher data density (100 data points) within the two week period. The evaporative method was found to produce repeatable results, with subsequent measurements of each substrate providing analogous measurements ($P > 0.9000$ and $P > 0.3700$ for the peat and bark substrate, respectively). There was little variation between the two methodologies for the peat substrate (0.004% difference in the area under the curves from 0 to −300 hPa). However, differences were observed between the methodologies for the bark substrate, with the percentage difference increasing with increasing water potential (9.6% at −100 hPa; 23.7% at −300 hPa). Additionally, the evaporative method measured a continued decrease in volumetric water content of the aged pine bark and sand substrate with increasing water potentials throughout the range of measurements, unlike the pressure extraction method, which has documented issues with loss of hydraulic connectivity between the sample and the plate in coarse highly porous organic substrates. Therefore, the pressure extraction method ceases to decrease in volumetric water content (≤ −65 hPa) resulting in a divergence in curves generated by the two methods. Both methods were found to have limitations while measuring substrate water content near saturation, with the pressure plate resistance to free drainage of water influencing measurements and the evaporative method continually underestimating the saturation point. As a result, both methods provided decreased volumetric water content measurements near saturation than when static physical properties were directly measured; therefore, moisture characteristic curves should be used collectively with static properties to correct for underestimation of total porosity and to better yield an understanding of the hydrophysical properties of a soilless substrate.

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[*] Corresponding author.
E-mail address: jsowen@vt.edu (J.S. Owen Jr.).

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1. Introduction

Fresh water is a limited natural resource, and it is a vital component of container crop production. A container nursery consumes upwards of 72 m^3 of water per acre each day during the growing season (Fulcher and Fernandez, 2013). The 2014 Census of Agriculture shows that specialty crop sales have increased by 18% since the previous census in 2009 with the vast majority of these crops spending at least a portion of their life cycles in containers (U.S. Department of Agriculture, 2015). Soilless substrates have been heavily relied upon for production of containerized crops for decades with their use in specialty crop production increasing (Raviv and Lieth, 2008). It is important that research be conducted to understand and engineer soilless substrates for production systems that more effectively utilize resources, namely water and mineral nutrients, in order for the containerized specialty crop industry to continue to flourish. A more in depth understanding of the hydraulic properties of soilless substrates may prove beneficial to this undertaking. Historically, research has focused on measuring and altering the static physical properties [total porosity (TP), measured maximum water holding capacity (container capacity; CC) and minimum of air space (AS)] of soilless substrates to optimize the relative ratio of air and water (Bilderback et al., 2005). However, more recently, Caron et al. (2014) emphasized the need to investigate dynamic properties when analyzing soilless substrates to correctly understand hydrology over the course of producing containerized crops. This approach would utilize moisture characteristic curves (MCCs) to understand soilless substrate dynamic properties as opposed to solely analyzing static physical properties which do not represent conditions during wetting or drying.

Moisture characteristic curves have been utilized by researchers to quantify hydrophysical properties and make inferences into the hydrology of soilless substrates since first described by Bunt (1961). A MCC is conventionally generated by applying incremental pressure increases to a substrate sample on a pressure plate to extract water that is held at varying tensions (Klute, 1986). The amount of water remaining at each pressure is used to calculate volumetric water content (Θ) associated with that pressure. The resulting data are interpreted as the relationship between water potential (Ψ) and Θ, referred to as the MCC, which differs between individual substrates. Data from MCCs have been used to make inferences of gas and water flux within a soilless substrate, with an emphasis on water available to produce containerized crops. Most notably, MCCs have been used to describe water availability for subirrigated containerized crops; defining readily available water as occurring between tensions of −10 to −100 hPa (Ψ_{10}–Ψ_{100}) and further partitioned into easily available water between tensions of −10 to −50 hPa (water occurring between Ψ_{10} to Ψ_{50}) and water buffering capacity (water occurring between Ψ_{50} to Ψ_{100}; de Boodt and Verdonck, 1972).

Additional methods to generate MCCs in mineral soils have been described by Dane and Hopmans (2002). One method, known as the evaporative method, was first proposed by Wind (1968) and later simplified by Schindler (1980). The simplified evaporative method involves simultaneously measuring Ψ and gravimetric water content of a sample as water evaporates from an exposed surface. This method can also be simultaneously used to calculate hydraulic conductivity. Wendroth et al. (1993) confirmed the application of evaporative method for mineral soils; however, the authors cautioned that soils with extreme textures (i.e. relatively small or large particle sizes) should be examined for suitability to utilize the evaporative method. Schindler and Muller (2006) more recently pronounced the need for increased data density in order to more accurately describe evaporative functions. Furthermore, Peters and Durner (2008) described uncertainties regarding low precision in hydraulic conductivity measurements at large values of Θ when using the evaporative method.

A device known as the Hyprop (Hydraulic property analyzer; UMS, Munich, Germany) recently became commercially available and is being utilized to measure the relationships between Θ, Ψ, and hydraulic conductivity in variably saturated porous media. The Hyprop utilizes a simplified evaporative method as described by Schindler et al. (2010) and yields increased data density which negates inaccuracies of the predictive method exposed by Schindler and Muller (2006) as well as Peters and Durner (2008). Schelle et al. (2013) compared multiple lab methodologies for obtaining MCCs of mineral soils including both the evaporative method and the traditional pressure plate method, concluding that in mineral soils the pressure plate method has the tendency to overestimate Θ. No such comparisons exist for highly porous organic soilless media. Recently, Schindler et al. (2016) published research in which MCCs for primarily peat-based substrates were measured utilizing the evaporative method. However, there were no comparisons to more traditional methodologies in order to address the cautions of Wendroth et al. (1993) for extreme particle sizes (i.e. soilless substrates).

The goal of this research was to determine whether the evaporative method for obtaining MCCs would be valid for coarse, highly porous, dominantly organic soilless substrates. The authors hypothesized that the evaporative method will provide repeatable data that is analogous to the pressure extraction method for organic soilless substrates, with continued measurements of diminishing volumetric water content as substrate water potential decreases beyond the water potential that substrate samples lose connectivity. Specific objectives were to: (1) Determine the capacity of the evaporative method to provide consistent, reproducible data for bark or peat based soilless substrates; and (2) compare MCCs obtained with the evaporative method to those obtained with pressure plates. The testing of these hypotheses will allow researchers to realize inaccuracies or concerns that may be associated with employing the new or existing technologies for measuring MCCs discussed in this paper. As such, this study provides an initial evaluation of dynamic property measurements for highly porous soilless substrates utilizing this new methodology.

2. Materials and methods

2.1. Static physical properties

Two different soilless substrates; a substrate primarily utilized in open air nursery production, composed of 9 aged pine bark (*Pinus taeda* L.; Carolina Bark Products, Seaboard, NC): 1 mason sand (Heard Aggregates, Waverly, VA; by volume); and a commercially available substrate traditionally used in greenhouse production, composed of *Sphagnum* peat moss and perlite (Fafard 1-P; Sungro, Agawam, MA) were used for this experiment. Henceforth they are referred to as bark and peat, respectively. Static physical properties including TP, CC, AS, and bulk density (D_b) were determined for each substrate using porometer analysis following procedures in Fonteno and Harden (2010) (Table 1). In addition, particle size distribution of 100 g oven dried samples were determined for three replicates of each substrate by passing the substrate through seven sieves (6.30, 2.00, 0.71, 0.50, 0.25, 0.11 mm openings) and a lower catch pan. Sieves and pan were shaken for 5 min with a Ro-Tap shaker (Rx-29; W.S. Tyler, Mentor, OH). The particles that were retained on each sieve that passed through the 0.11 mm sieve were weighed individually to determine the particle size distribution (Table 1).